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(54) **METHOD AND APPARATUS FOR OPTIMIZING A RELATIONSHIP BETWEEN FIRE ENERGY AND DROP VELOCITY IN AN IMAGING DEVICE**

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(52) **U.S. Cl.** **347/19**; 347/14
(58) **Field of Search** 347/14, 19

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,686,539 A		8/1987	Schmidle et al.	
4,872,028 A	*	10/1989	Lloyd	347/19
5,109,234 A		4/1992	Otis, Jr. et al.	
5,428,376 A		6/1995	Wade et al.	
5,526,027 A		6/1996	Wade et al.	
5,642,142 A		6/1997	Bohorquez	
5,682,185 A		10/1997	Wade et al.	
5,751,302 A		5/1998	Rezanka	
5,886,716 A		3/1999	Heinzl et al.	
5,997,124 A	*	12/1999	Capps et al.	347/14
6,076,981 A		6/2000	Hayama et al.	
6,116,717 A	*	9/2000	Anderson et al.	347/19
6,151,050 A		11/2000	Hosono et al.	
6,183,056 B1		2/2001	Corrigan et al.	
6,244,682 B1		6/2001	Walker et al.	
6,467,867 B1	*	10/2002	Worthington et al.	347/19
2002/0030708 A1	*	3/2002	Yoshida	347/19

* cited by examiner

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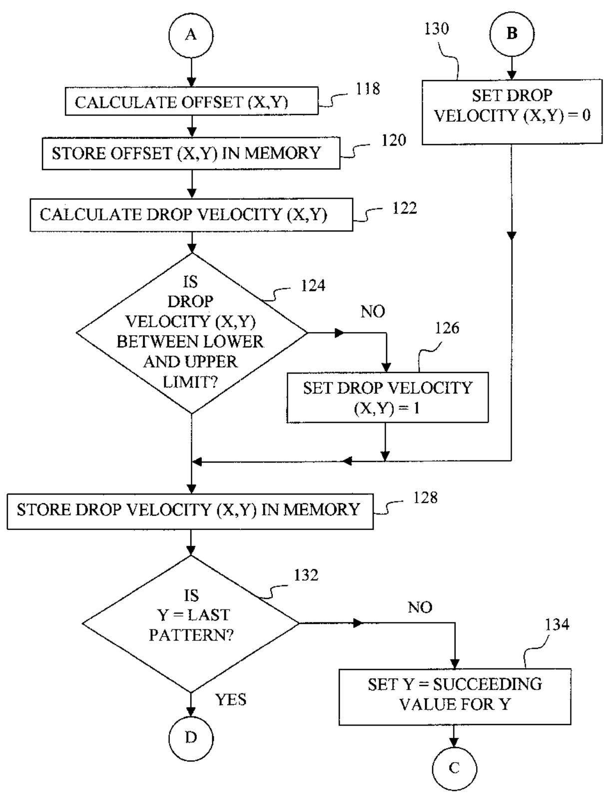
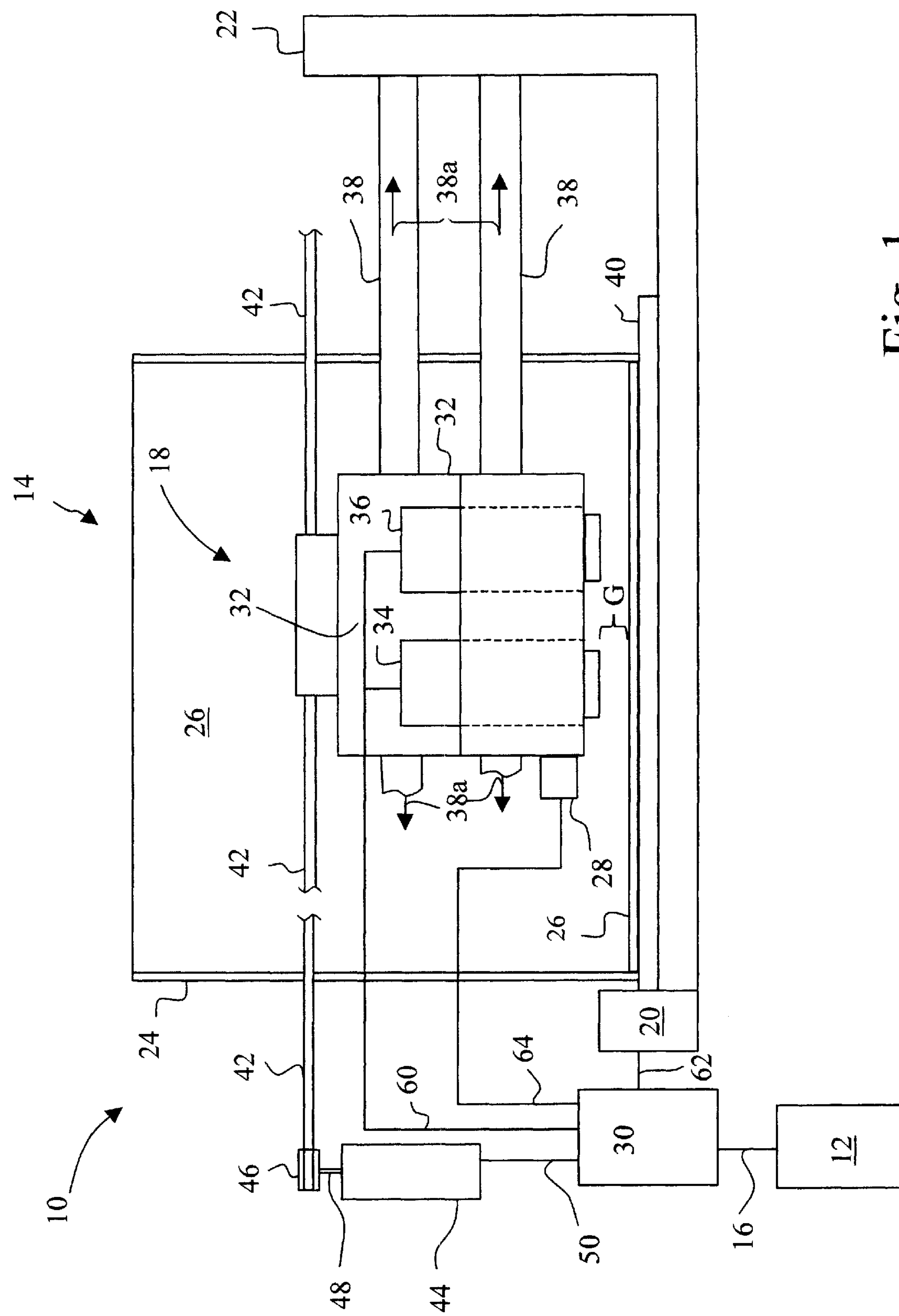
(57) **ABSTRACT**

A method of optimizing a relationship between fire energy and drop velocity associated with a printhead is provided. A test pattern is printed by selectively supplying energy distribution signals to a plurality of actuators of the printhead. The energy distribution signals have distinct energy profiles. The test pattern is scanned to obtain drop velocity information corresponding to the energy distribution signals. Based on the drop velocity information, an energy profile is determined that optimizes the relationship between fire energy and drop velocity.

23 Claims, 7 Drawing Sheets





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38a
38a
40
42
42
42
44
46
48
50
60
62
64
G

Fig. 1

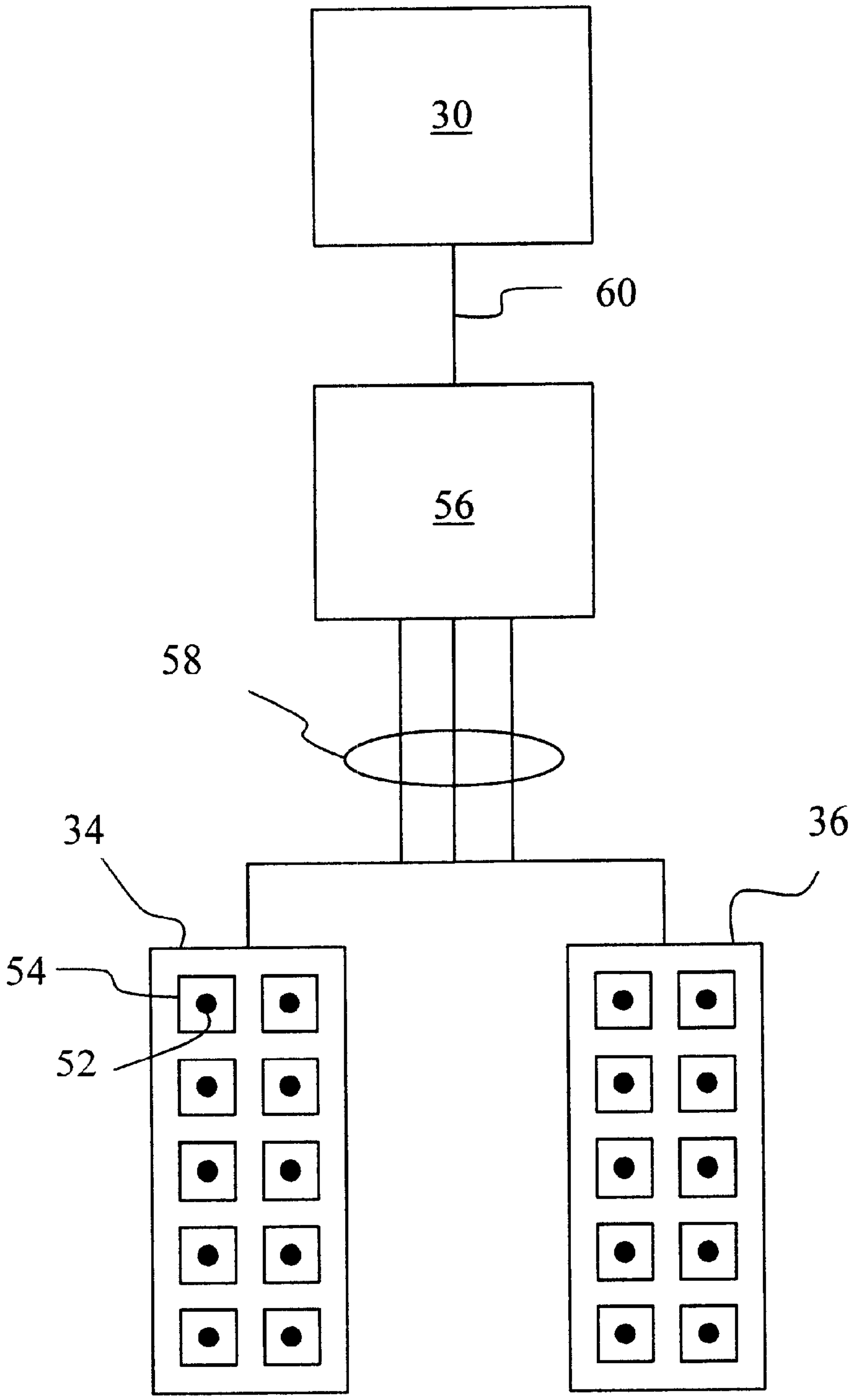

Fig. 2

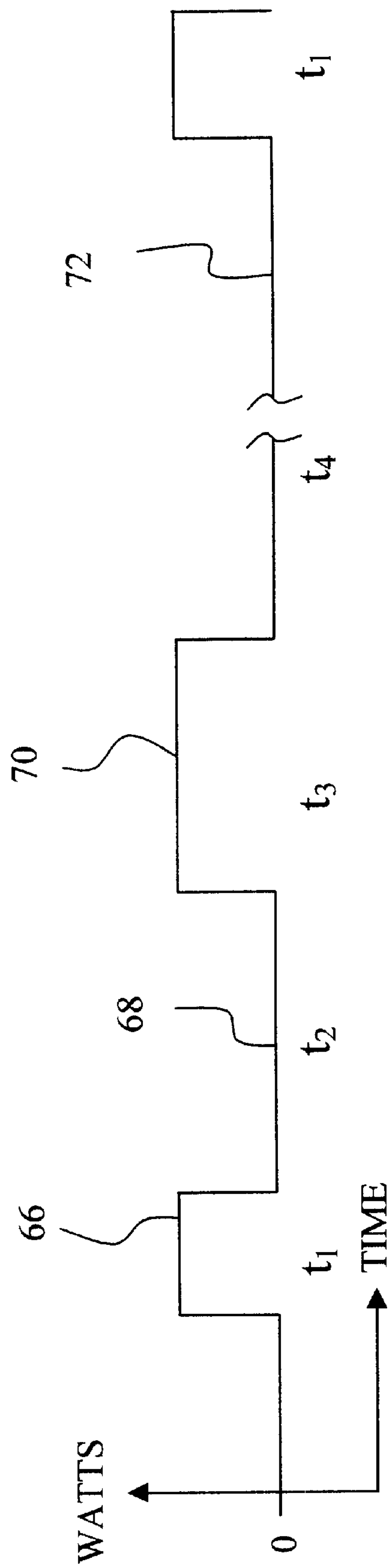

Fig. 3

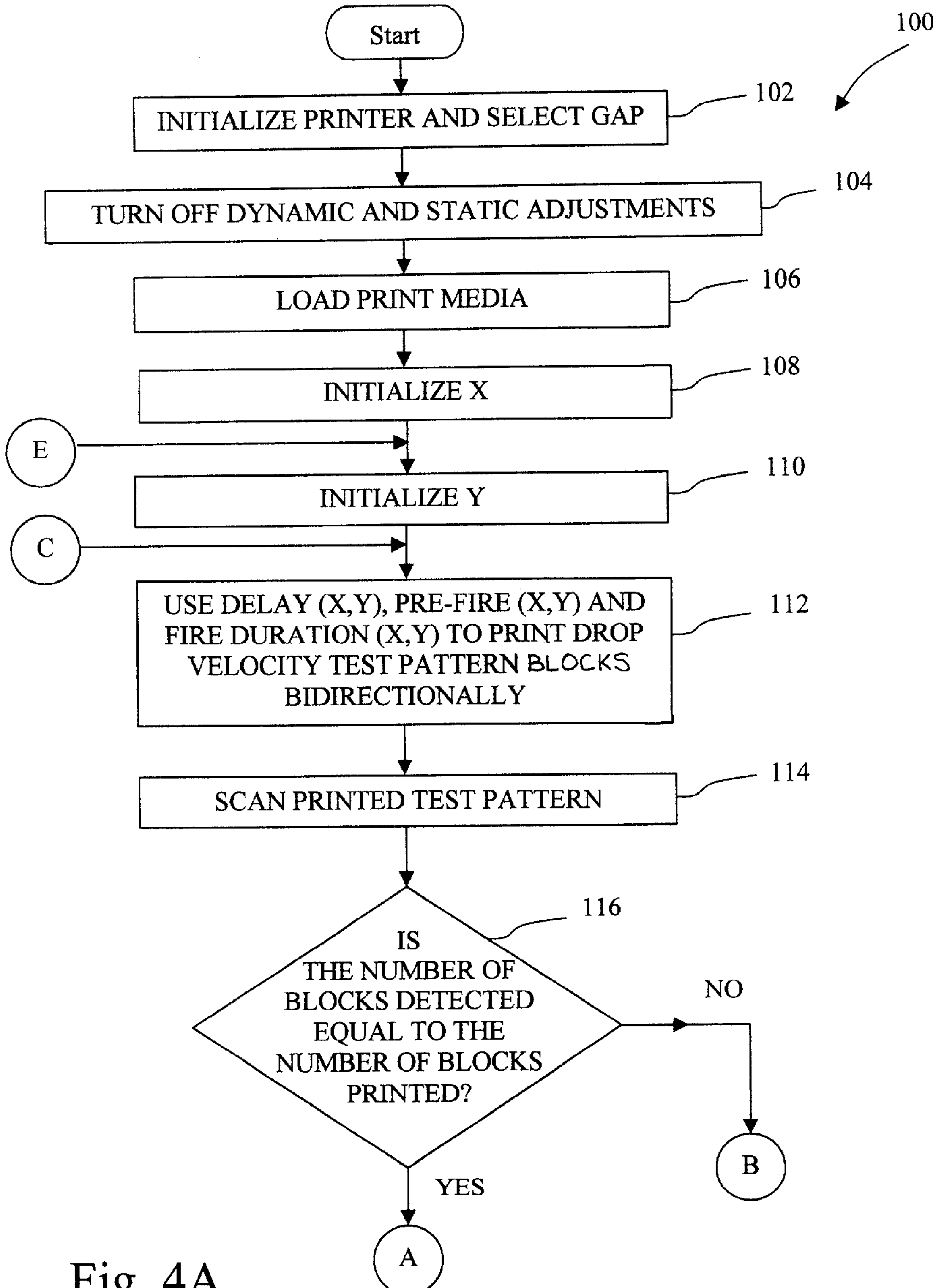
100
Start
INITIALIZE PRINTER AND SELECT GAP
102
TURN OFF DYNAMIC AND STATIC ADJUSTMENTS
104
LOAD PRINT MEDIA
106
INITIALIZE X
108
E
INITIALIZE Y
110
C
USE DELAY (X,Y), PRE-FIRE (X,Y) AND FIRE DURATION (X,Y) TO PRINT DROP VELOCITY TEST PATTERN BLOCKS BIDIRECTIONALLY
112
SCAN PRINTED TEST PATTERN
114
IS THE NUMBER OF BLOCKS DETECTED EQUAL TO THE NUMBER OF BLOCKS PRINTED?
116
NO
B
YES
A

Fig. 4A

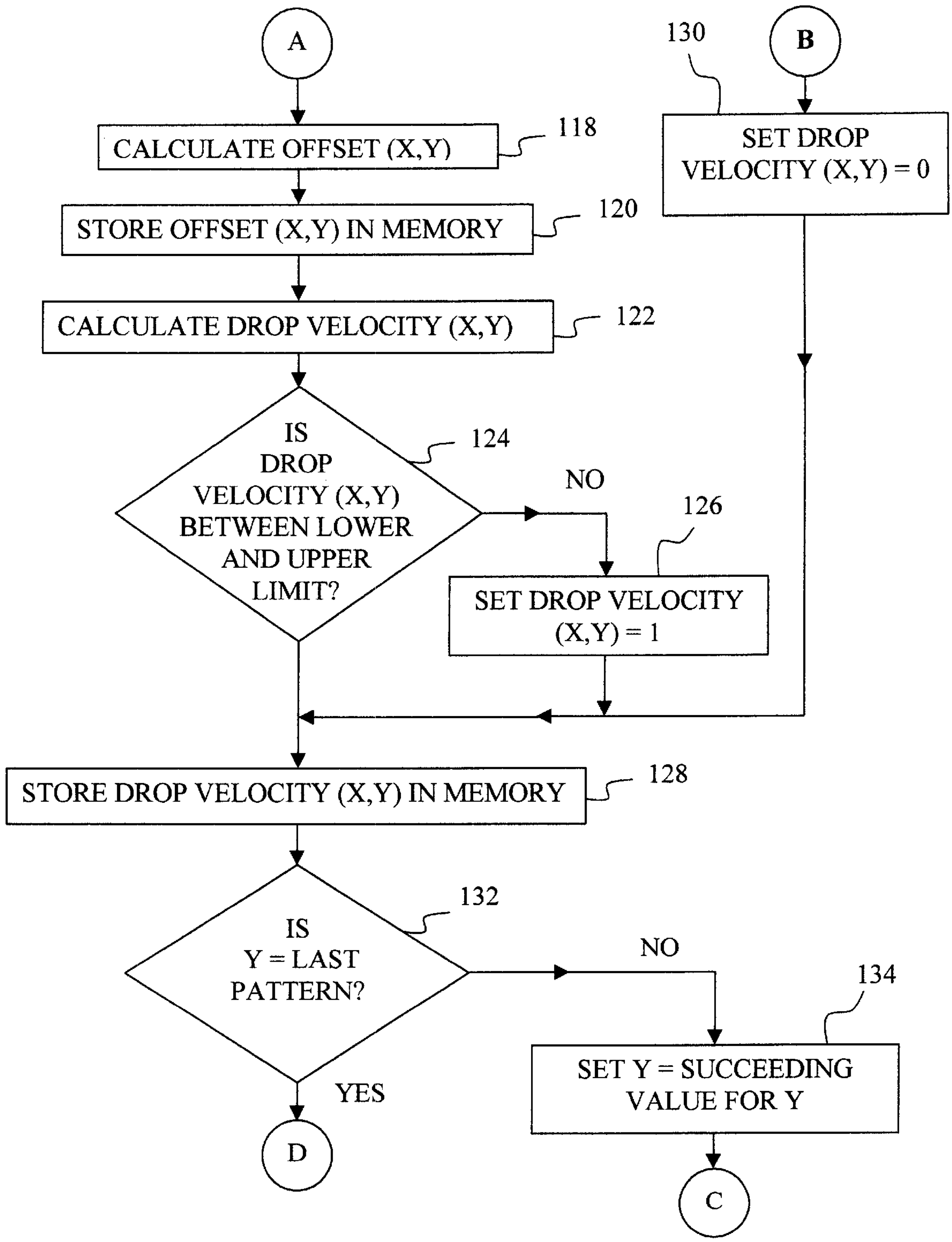
A
B
130
CALCULATE OFFSET (X,Y)
118
SET DROP VELOCITY (X,Y) = 0
STORE OFFSET (X,Y) IN MEMORY
120
CALCULATE DROP VELOCITY (X,Y)
122
IS DROP VELOCITY (X,Y) BETWEEN LOWER AND UPPER LIMIT?
124
NO
126
SET DROP VELOCITY (X,Y) = 1
STORE DROP VELOCITY (X,Y) IN MEMORY
128
IS Y = LAST PATTERN?
132
NO
134
SET Y = SUCCEEDING VALUE FOR Y
YES
D
C

Fig. 4B

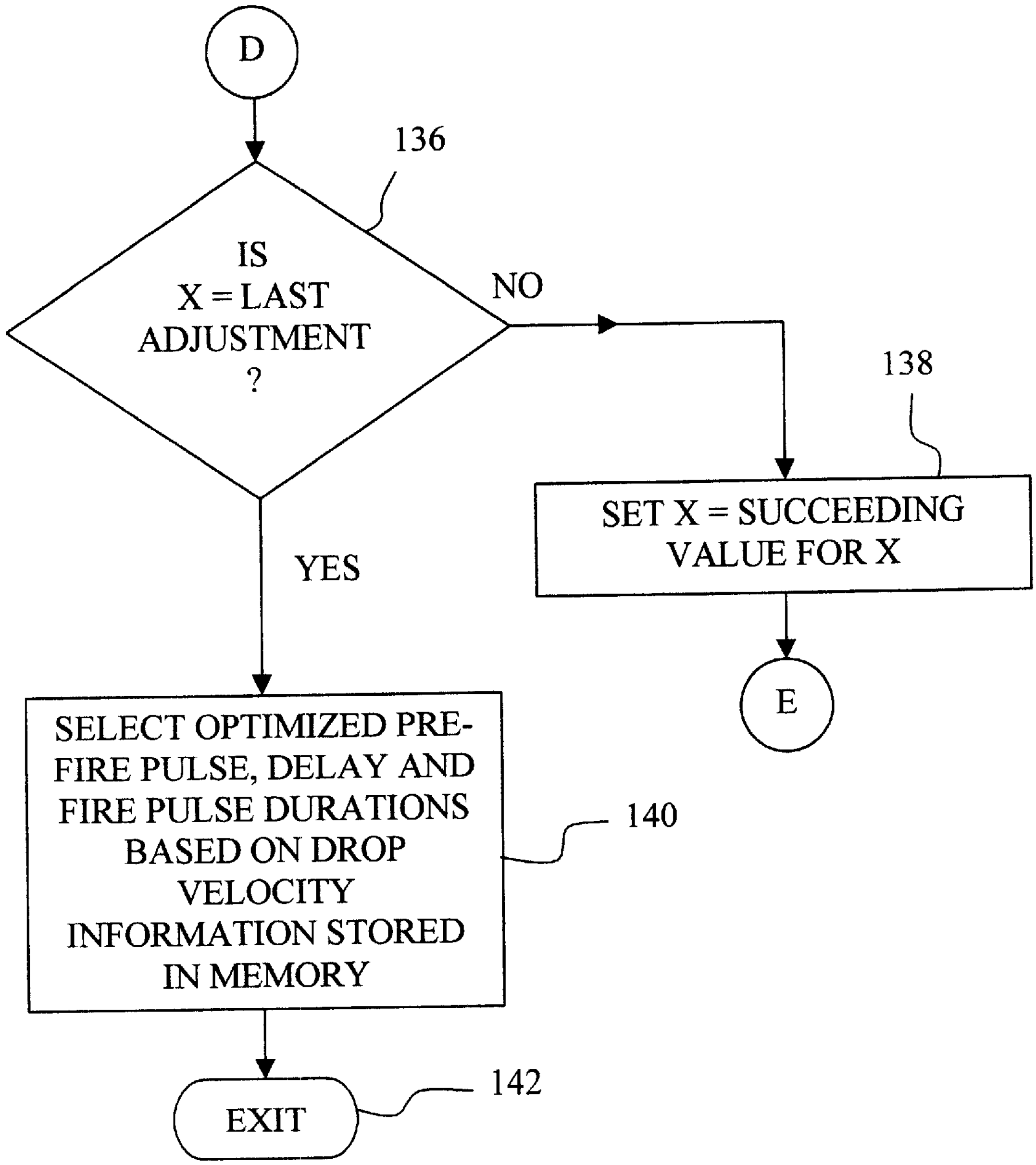
D
136
IS
X = LAST
ADJUSTMENT
?
NO
138
SET X = SUCCEEDING
VALUE FOR X
E
YES
SELECT OPTIMIZED PRE-
FIRE PULSE, DELAY AND
FIRE PULSE DURATIONS
BASED ON DROP
VELOCITY
INFORMATION STORED
IN MEMORY
140
EXIT
142

Fig. 4C

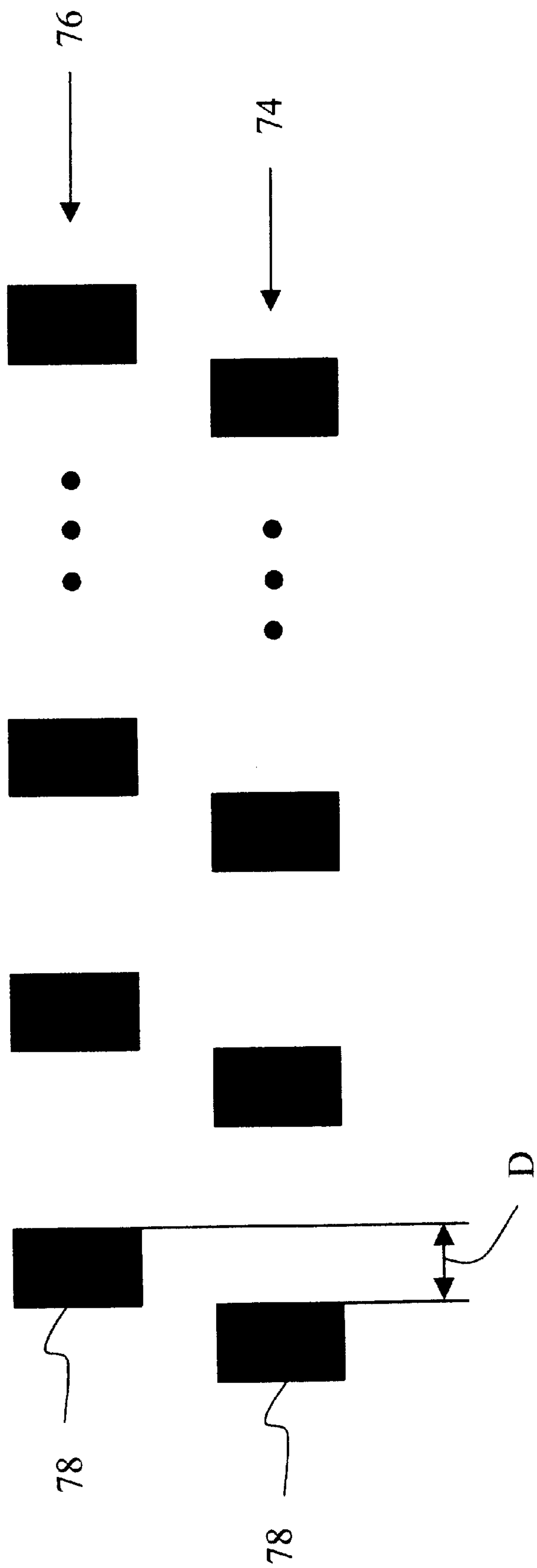

Fig. 5

METHOD AND APPARATUS FOR OPTIMIZING A RELATIONSHIP BETWEEN FIRE ENERGY AND DROP VELOCITY IN AN IMAGING DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method and apparatus for optimizing a relationship between fire energy and drop velocity in an imaging device, and, more particularly, in one embodiment, to a method and apparatus for adjusting pre-fire and fire pulses used to jet ink from a printhead in an imaging device.

2. Description of the Related Art

An ink jet printer typically includes a printhead, which is carried by a carrier. The printhead is fluidly coupled to an ink supply. Such a printhead includes a plurality of nozzles having corresponding ink ejection actuators, such as heater elements.

Ink is jetted from the nozzles onto a print medium at selected ink dot locations within an image area. The carrier moves the printhead across the print medium in a scan direction while the ink dots are jetted onto selected pixel locations within a given raster line. Between passes of the printhead, the print medium is advanced a predetermined distance and the printhead is again moved across the print medium.

Ink jet printers may utilize a single printhead, or multiple printheads. For example, some ink jet printing systems utilize a monochrome ink cartridge including a monochrome, e.g. black, printhead, and a color ink cartridge including a color printhead having cyan, magenta and yellow nozzle groups. In another type of ink jet printing system, each printhead is connected to a respective remote ink supply.

The manufacture of printheads involves certain manufacturing tolerances resulting in manufacturing variations (e.g., variations in sheet resistance of the material used in heater elements; mask alignment variations, which lead to variations in the width and length of heater elements; the rise and fall times of transistors that drive the heater elements; the thickness of the layer between the heater element and the ink, which influences heat transfer to the ink; the ink chemistry; and the voltage level of the power source), which in turn result in printheads that require differing amounts of energy to attain a drop velocity deemed suitable (e.g., high enough) for attaining a desired print quality. Thus, typically, from printhead to printhead, the amount of energy required to attain a suitable drop velocity varies.

Because of these manufacturing variations, an energy level for driving such printheads will be selected so that most printheads will attain a certain minimum drop velocity (e.g., 400–600 inches per second). This energy level is a statistical average value meant to encompass the largest range of printhead variations possible. Because the same predetermined amount of energy is used for each printhead, the energy is not optimized for a particular printhead.

One problem with this manner of ink delivery is that variations in the printheads lead to inefficiencies in printhead operation. The result is drop velocity variations and difficulty in maintaining nominal head temperatures. Another problem is that driving ink jet heaters at an energy level required to jet ink at an acceptable drop velocity means overdriving some printheads. By overdriving printheads, the overdriven nozzles can fail prematurely due to electromigration of the heater element.

What is needed in the art is a method and apparatus that reduces variations in drop velocities among a type of printhead, and/or provides for fire energy adjustment for the printhead.

SUMMARY OF THE INVENTION

The present invention provides, in one embodiment, an apparatus and method for measuring ink drop velocities and adjusting the energy used to eject ink.

The invention, in one form thereof, is directed to a method of adjusting fire energy supplied to an actuator of a printhead of an ink jet printer. The method includes printing a test pattern on a print media by selectively supplying energy distribution signals to a plurality of actuators of the printhead, the energy distribution signals having distinct energy profiles; scanning the test pattern to obtain offset values, each of the offset values representative of a distance between at least two corresponding portions of the test patterns; calculating drop velocities from the offset values; and selecting from the energy distribution signals an energy distribution signal that corresponds with an optimal one of the drop velocities.

The invention, in another form thereof, is directed to an ink jet printer. The ink jet printer includes a controller, a sensor and a printhead having actuators that are capable of jetting ink with a drop velocity when an energy distribution signal having a fire energy is supplied. The controller is capable of communicating with the printhead and the sensor. The controller employs a method including printing a test pattern on a print media by selectively supplying energy distribution signals to a plurality of the actuators of the printhead, the energy distribution signals having distinct energy profiles; scanning the test pattern with the sensor to obtain offset values, each of the offset values representative of a distance between at least two corresponding portions of the test pattern; calculating drop velocities from the offset values; and selecting from the energy distribution signals an energy distribution signal that corresponds with an optimal one of the drop velocities.

The invention, in yet another form thereof, is directed to an imaging device including a carrier, a printhead carrier by the carrier, a sensor carried by the carrier, and a controller communicatively coupled with the printhead and the sensor. The controller is configured to print an image on a sheet of print media. The image includes a test pattern. The controller employs an energy distribution signal adjustment method to determine an energy profile for the printhead.

The aforementioned energy distribution signal adjustment method includes printing the test pattern using distinct energy profiles; scanning the test pattern with the sensor to obtain offset values, wherein a respective one of the offset values is representative of a distance between corresponding portions of the test pattern; and calculating drop velocities corresponding to the distinct energy profiles based on the offset values; Based on the drop velocities, an optimal energy profile is determined. The optimal energy profile is determined by using the drop velocities to determine when an incremental change in energy corresponds with a disproportionate change in drop velocity.

The invention, in yet another form thereof, is directed to a method of optimizing an energy distribution signal for use by a printhead including a plurality of heater elements. The method includes printing a test pattern using energy profiles; scanning the test pattern to obtain offset values, wherein a respective one of the offset values is representative of a distance between corresponding portions of the test pattern; and calculating drop velocities corresponding to the energy profiles, wherein the optimal energy profile is determined by using the drop velocities to determine when an incremental change in energy corresponds with a disproportionate change in drop velocity. An energy distribution signal corresponding to the optimal energy profile is selected.

The invention, in still a further form thereof, is directed to a method of optimizing a relationship between fire energy and drop velocity. In such a method, a test pattern is printed by selectively supplying energy distribution signals to a plurality of actuators of a printhead. The energy distribution signals have distinct energy profiles. The test pattern is scanned to obtain drop velocity information corresponding to the energy distribution signals. Based on the drop velocity information, an energy profile is determined that optimizes the relationship between fire energy and drop velocity.

An advantage of certain embodiments of the present invention is that the fire energy used in an ink jet printer printhead is optimized thereby increasing the life of the printhead.

Another advantage of certain embodiments of the present invention is that the printhead heats less; thus, throughput levels of the printer can increase since the time required to cool a printhead is reduced or eliminated.

Still yet another advantage of certain embodiments of the present invention results from allowing thin film printheads to run open loop without any temperature sensor resistor being required.

A further advantage of certain embodiments of the present invention is that variations that occur in the manufacture of the printhead can be compensated.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned and other features and advantages of this invention, and the manner of attaining them, will become more apparent and the invention will be better understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

FIG. **1** is diagrammatic representation of an imaging system employing an embodiment of the method of the present invention;

FIG. **2** is a diagrammatic representation of circuitry for supplying energy pulses to the heater elements of the printheads of FIG. **1**.

FIG. **3** depicts pulse widths associated with fire energy of the ink jet printer of FIG. **1**;

FIGS. **4**A, **4**B and **4**C represent a flowchart of a method employed by the ink jet printer of the imaging system of FIG. **1**; and

FIG. **5** depicts a test pattern printed on a print media by the ink jet printer of the imaging system of FIG. **1**.

Corresponding reference characters indicate corresponding parts throughout the several views. The exemplification set out herein illustrates one embodiment of the invention, in one form, and such exemplification is not to be construed as limiting the scope of the invention in any manner.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings and more particularly to FIG. **1**, there is shown an imaging system **10** embodying the present invention. Imaging system **10** includes a computer **12** and an imaging device in the form of an ink jet printer **14**. Computer **12** is communicatively coupled to ink jet printer **14** by way of a communications link **16**. Communications link **16** may be, for example, an electrical, an optical or a network connection.

Computer **12** is typical of that known in the art, and includes a display, an input device such as a keyboard, a processor and associated memory. Resident in the memory of computer **12** is printer driver software. The printer driver software places print data and print commands in a format that can be recognized by ink jet printer **14**.

Ink jet printer **14** includes a carrier system **18**, a feed roll unit **20**, a frame **22**, a media source **24** holding a sheet of print media **26**, a sensor **28** and a controller **30**. Carrier system **18** includes a printhead carrier **32**, a black printhead **34**, a color printhead **36**, guide rods **38**, a carrier transport belt **42**, a carrier motor **44**, a driven pulley **46** and a carrier motor shaft **48**. Carrier system **18** and printheads **34** and **36** may be configured for unidirectional printing or bi-directional printing.

Printhead carrier **32** is guided by the pair of guide rods **38**. Guide rods **38**, also known as carrier support **38**, are connected to frame **22**. Axes **38***a*, associated with guide rods **38**, define a bi-directional printing/scanning path of printhead carrier **32**. Printhead carrier **32** is slidingly connected to carrier support **38**. Printhead carrier **32** is also connected to a carrier transport belt **42** that is driven by carrier motor **44** by way of driven pulley **46**.

Controller **30** includes, for example, a processor and associated memory for executing process steps to control the operation of ink jet printer **14**. At a directive of controller **30**, printhead carrier **32** is transported in a reciprocating manner, along guide rods **38**. Carrier motor **44** can be, for example, a direct current drive or a stepper motor.

The reciprocation of printhead carrier **32** transports ink jet printheads **34** and **36** across the sheet of print media **26** along a bi-directional path **38***a*. This reciprocation occurs in a direction that is parallel with bi-directional printing/scanning path **38***a* and is also commonly referred to as the main scan, or horizontal, direction. At the direction of controller **30**, the sheet of print media **26** is fed by feed roll unit **20**, including feed roller **40**, in an indexed manner under ink jet printheads **34** and **36**.

Additionally referring to FIG. **2**, printheads **34** and **36** each have a plurality of individually selectable nozzles **52**, represented by dots, for effecting the controllable ejection of ink toward the sheet of print media **26**. Associated with each nozzle is an actuator, such as heater element **54**, represented by a square. Controller **30** is connected to a printhead driver **56** via communication link **60**. Printhead driver **56** is connected to heater elements **54** of printheads **34**, **36** via a printhead cable **58**. Thus, controller **30** is controllably coupled to printheads **34** and **36** to thereby control the fire energy supplied to each heater element **54**.

Also attached to printhead carrier **32** is sensor **28**. Sensor **28** may be for example an optical sensor that includes a light emitter and a light detector. Light emitted by sensor **28** is reflected off of the sheet of print media **26** and is received by the light detector of sensor **28**. Thus, sensor **28** can provide information to controller **30** relating to the location and quality of the printing effected by printheads **34** and **36**. In an exemplary embodiment, sensor **28** can be used to align printheads **34** and **36**.

Feed roll unit **20** advances the sheet of print media **26** through ink jet printer **14** via rotation of feed roller **40**. Feed roll unit **20** is controllably linked to controller **30**. Media source **24** is connected to frame **22** and is configured and arranged to supply individual sheets of print media **26** to feed roll unit **20**, which in turn transports the sheets of print media **26** during a printing operation.

Controller **30** is linked to carrier motor **44** by way of a communications link **50**. Controller **30** controls the speed direction and acceleration of carrier transport belt **42**, which thereby controls the direction speed and acceleration of printhead carrier **32**. Controller **30** is communicatively linked with black printhead **34** and color printhead **36** by way of communications link **60**. Controller **30** selectively actuates one or more of heater elements **54** of printheads **34** and/or **36** by way of communications link **60** to effect the printing of an image on the sheet of print media **26**.

Controller **30** is connected with feed roll unit **20** by way of communications link **62** thereby passing commands for controlling the feeding of the sheet of print media **26** through ink jet printer **14**. Controller **30** is also communicatively coupled to sensor **28** by way of communications link **64**. Information from sensor **28** is passed by way of communications link **64** to controller **30**.

The fluidic properties of the ink in printheads **34** and **36** play a role in print quality and throughput. The maximum frequency at which printheads **34** and **36** can eject an ink drop from each of nozzles **52** is primarily determined by how quickly an ink chamber (not shown) can refill. The refill time is related to the force of nucleation.

By over-driving some heater elements **54** and ejecting too much ink, the ink chamber cannot refill quickly enough to print at a given frequency. This means that either the printhead will not eject a drop of ink or that it will eject a drop of the incorrect mass, both of which decrease print quality. By minimizing the nucleation force, thereby minimizing refill time, print quality improves. Minimizing the refill time also increases the frequency at which printheads **34** or **36** can operate, allowing printhead carrier **32** to travel at an increased velocity, thereby, advantageously, raising throughput.

"Fire energy" refers to the total amount of energy (in joules, for example) supplied by an energy distribution signal to an actuator, such as heater element **54**, to jet a drop of ink. Fire energy can be adjusted, for example, by adjusting a duration of a pre-fire and/or a fire pulse of an energy distribution signal supplied to heater element **54**. A pulse of brief duration supplies less total energy to a heater element than a lengthier pulse duration. A printhead according to one embodiment of the present invention strives to optimize a relationship between drop velocity and fire energy by using a pulse duration(s) that attains a suitable drop velocity with a minimal amount of energy.

The mechanisms behind the velocity/energy response relate to the dynamics of bubble formation and expansion. As a bubble forms in printhead **34** or **36**, the bubble wall expands outward extremely quickly. The bubble itself is filled with a thermally insulating water vapor. This vapor separates and isolates the bubble wall from the heater element **54** nearly instantaneously.

Because of this condition, additional energy supplied to the heater after the onset of nucleation has little or no effect on expansion of the bubble wall. It is the rate of expansion of the bubble wall that provides the pressure pulse that ejects ink from the respective nozzle of printhead **34** or **36**. The magnitude of the pressure pulse determines the ink drop velocity. Energy supplied to heater element **54** after nucleation is merely dissipated as heat and serves to degrade the performance of printhead **34** or **36**.

By varying the duration of a fire pulse and/or a pre-fire pulse, for example, and measuring the corresponding drop velocity attained, a point where adding additional energy provides only marginal (or no) changes in drop velocity can be determined. Once this point is determined, an optimal duration (e.g., a duration closest to this point) can be selected for use with the printhead in future printing, thereby optimizing the relationship between fire energy and drop velocity.

Referring to FIG. **3**, there is shown an exemplary energy profile for an energy distribution signal including a pre-fire pulse **66**, a delay **68**, a fire pulse **70**, and a recharge time **72** that is supplied to heater element **54** to eject ink from a respective nozzle. The time interval of pre-fire pulse **66** has a duration t_1. In a similar manner the durations of delay **68**, fire pulse **70** and recharge time **72** are, respectively, t_2, t_3 and t_4. The amplitude of pulses **66** and **70** are each typically fixed but are not necessarily equal.

The fire energy consists of the total energy of pre-fire pulse **66** and fire pulse **70**. Pre-fire duration t_1, delay duration t_2, fire pulse duration t_3, and recharge duration t_4 can be varied and adjusted to optimize the drop velocity (e.g., maximize it), and to minimize the amount of energy expended through pulses **66** and **70**. In one embodiment, pulse durations t_1 and t_3 can be varied to minimize energy consumption. For example, pre-fire duration t_1, delay duration t_2 and fire pulse duration t_3 can be incrementally varied using, for example, predetermined values to optimize a relationship between drop velocity and fire energy.

Referring to FIGS. **4A**, **4B** and **4C** there is shown a block diagram representing a method according to one embodiment of the present invention used to determine an optimal energy distribution signal having an energy profile including pre-fire duration t_1, delay duration t_2 and pulse fire duration t_3. The method of FIGS. **4A–4C** is depicted by a plurality of processing steps, hereinafter referred to as process **100**, which may be executed by controller **30**. Alternatively, process **100** can be executed by computer **12** as it interacts with ink jet printer **14**.

Process **100** can be utilized to optimize, for example, pre-fire duration t_1, delay duration t_2 and pulse fire duration t_3 for printheads **34** and/or **36**, and durations t_1, t_2 and t_3 may differ as between printhead **34** and printhead **36**. Process **100** may be initiated each time one of printhead **34** or **36** is changed. Also, process **100** may be periodically initiated to re-optimize a relationship between drop velocity and fire energy for printheads **34** and/or **36**. Process **100** will be described hereinafter with respect to printhead **36**.

At step **102**, ink jet printer **14** is initialized and printhead gap G relating to the printhead of interest is determined. Printhead gap G represents the distance from, for example, the sheet of print media **26** to the surface of color printhead **36**. As described later herein, gap G can be used to help determine drop velocity.

Printhead gap G may be fixed. Alternatively, gap G may be adjustable, and selected by an operator. In one embodiment of the present invention, a gap G can be predetermined for a particular combination of printer and printhead.

At step **104**, controller **30** turns off dynamic and static adjustments relative to printhead **36**, thereby allowing a test pattern to be printed on the sheet of print media **26** without any of the static or dynamic compensations, which are stored by controller **30**. Alternatively, controller **30** can account for the adjustments and compensate therefor. At step **106**, controller **30** issues a command to feed roll unit **20** causing it to feed a sheet of print media **26** into ink jet printer **14**.

At step **108**, controller **30** initializes a variable X to an initial value, where X might represent a type of adjustment that is being incremented (e.g., a black pre-fire pulse, a black fire pulse, a color pre-fire pulse or a color fire pulse). Typically, a pre-fire pulse will be adjusted prior to adjusting a corresponding fire pulse. Step **110**, similar to step **108**, initializes a variable Y, where Y might represent a specific increment (e.g., in energy). For example, Y might represent pulse duration increments of about 50–75 ns. Each increment of Y can relate to a particular portion of a test pattern to be printed on a sheet of print media for a particular adjustment type X. Variable X and Y are used as control variables to control looping of process **100**.

At step **112**, controller **30** prints at least part of a test pattern using an energy distribution signal having an energy profile corresponding to a respective combination of variables X and Y. The energy distribution signal could be predetermined or might be generated as part of an algorithm. As each of the various combinations of X and Y variables are indexed (as further described below), a different energy distribution signal with a distinct energy profile is used to print at least a portion of a test pattern.

According to one embodiment of the present invention, only energy distribution signals that will eject ink regardless of manufacturing variability of the printhead are used (e.g., for the sake of error checking data that will be acquired). Moreover, according to an exemplary embodiment of the invention, the printhead is ran at less that its maximum frequency (e.g., a constant frequency) when printing the test pattern.

With reference to FIG. **5**, there is shown an exemplary test pattern comprising a set of test subpatterns **74** and **76**, each including several blocks **78**. Each of blocks **78** may, for example, be a 2 mm by 4 mm rectangle. According to one embodiment of the present invention, each of blocks **78** is printed using all of the heaters that can be actuated with the signal being optimized.

First test subpattern **74** can be printed by printhead **36** in one direction as carrier **32** transports printhead **36** in a horizontal direction. Second test subpattern **76** can be printed in another direction by printhead **36** as carrier **32** transports printhead **36** in a horizontal direction opposite to the direction in which first test subpattern **74** was printed. Alternatively, test subpatterns **74** and **76** may be interleaved or in some other form, such as moiré patterns.

In one embodiment of the present invention, a respective set of test subpatterns **74** and **76** is printed using an energy distribution signal having an energy profile corresponding to a respective combination of variables X and Y. In another embodiment, a respective set of corresponding blocks **78** in a set of test subpatterns **74** and **76** is printed using an energy distribution signal having an energy profile corresponding to a respective combination of variables X and Y. One advantage of such an embodiment could include reducing the test pattern down to only one set of test subpatterns **74** and **76**.

At step **114**, controller **30** directs the movement of printhead carrier **32** and reads information supplied by sensor **28**. The test subpatterns **74** and **76** printed on the sheet of print media **26** are scanned by sensor **28**, and the information gathered is sent to controller **30**. Although process **100** indicates that a set or portion of test subpatterns are scanned before a next set or portion of test subpatterns is printed, alternative embodiments of the present invention could print all or a group of such sets before scanning the same.

When test subpatterns **74** and **76** are printed, each in a different direction, an offset distance D between corresponding blocks **78** of test subpattern **74** and test subpattern **76** can be observed. Offset distance D is a measure of the shift between test subpattern **74** and test subpattern **76**, which are printed in opposite directions. Offset distances D can be determined by sensor **28** detecting an attribute of blocks **78** such as the edges of corresponding blocks **78**. Whereas several blocks **78** are printed, several offset distances D (also referred to herein as offset values) can be sent to controller **30** for each set of test subpatterns **74** and **76** printed.

At step **116**, controller **30** determines if the number of blocks **78** detected by sensor **28** is equal to the number of blocks **78** printed by ink jet printer **14**. If the number of blocks **78** detected is not equal to the number of blocks **78** printed, process **100** continues to step **130**. If the number of blocks **78** detected is equal to the number of blocks **78** printed, then process **100** continues to step **118**. The purpose of this test is to determine if the pattern blocks have all been printed, otherwise it is assumed that the print velocities were insufficient or caused such degradation of performance that the pulse durations (e.g., t_1 and t_3) are not appropriate for use with printhead **36**.

At step **118**, controller **30** calculates a value for the offset associated with the particular durations t_1, t_2 and t_3 that correspond to a particular combination of X and Y. At step **120**, controller **30** stores the offset value for the combination of X and Y (e.g., in the controller memory).

At step **122**, controller **30** calculates drop velocity for the particular X, Y values of this implementation of the loop. Drop velocity can be represented as a function of gap G, the velocity CV of printhead carrier **32** and the offset (X,Y). An exemplary equation for calculating drop velocity DV follows:

$$DV(X,Y)=(G*2CV)/(\text{Offset}(X,Y))$$

At step **124**, controller **30** determines if the drop velocity associated with a particular combination of X and Y is between a lower limit and an upper limit. The lower limit being, for example, 200 inches per second and the upper limit being, for example, 700 inches per second. If the drop velocity is between the lower and upper limits, then process **100** continues to step **128**, otherwise process **100** continues to step **126**.

At step **126**, controller **30** sets a drop velocity variable for the combination of X and Y index variables equal to the value of one. The setting of drop velocity (X,Y) equal to one is for use by controller **30**, to mark the fact that drop velocity (X,Y) was outside of the prescribed limits. Following step **126**, process **100** continues to step **128**.

If, at step **116**, the number of blocks **78** detected is not equal to the number of blocks **78** printed, at step **130**, the drop velocity variable for that combination of X and Y is set to a value of zero. The setting of drop velocity (X,Y) to zero is for use by controller **30** to mark the fact that at least some of the pattern blocks **78** were not printed. Following the step **130**, process **100** continues to step **128**.

At step **128**, controller **30** stores drop velocity (X,Y) in controller memory. Alternatively, controller **30** can store drop velocity information (e.g., drop velocity (X,Y) and/or offset (X,Y)) in a memory contained in computer **12**. Process **100** then continues to step **132**.

At step **132**, controller **30** determines if index variable Y is equal to the last increment for a particular adjustment type X. If index variable Y is not equal to the last increment then process **100** continues to step **134**. If index variable Y is equal to the last increment then process control continues to step **136**.

At step **134**, controller **30** sets index variable Y equal to a succeeding value for Y. Process **100** then returns to step **112**.

At step **136**, it has already been determined, at step **132**, that Y is equal to the last increment in the index sequence. At step **136**, it is determined whether index variable X is equal to the last adjustment type. If index variable X is equal to the last adjustment type, then process **100** continues to step **140**. If index variable X is not equal to the last adjustment type, then, at step **138**, index variable X is set to the succeeding value for index variable X, and process **100** returns to step **110**.

At step **140**, controller **30** determines an energy distribution signal having optimized pre-fire pulse durations t_1, delay durations t_2 and fire pulse durations t_3, based upon drop velocity (X,Y) information stored in memory. Drop velocities increase with an increase in fire energy to a certain point, and thereafter additional energy supplied has a marginal or no effect on drop velocity. A marginal effect is indicated when, for example, an increase in the duration of fire pulse **70**, for example, does not result in a drop velocity increase substantially proportional to the increase observed between drop velocities (X,Y) reflecting preceding adjacent durations t_3.

For example, an optimal relationship might be determined by analyzing for the knee of a curve representing drop velocity versus fire energy (or duration). In another embodiment, as offset can be presumed to be the only variable in the aforementioned exemplary equation for determining drop velocity (e.g., gap G and carrier velocity CV can be presumed constant), offset values can be directly used, instead of their corresponding drop velocities, to determine an optimal relationship. As used herein, a "knee" of a curve can be defined as a point or area on a curve where the curvature of the curve is a maximum (or, alternatively, where the radius of curvature is a minimum). In one embodiment of the present invention, all of the measured offsets, or drop velocities determined therefrom, are considered in the determination

Optimized pre-fire pulse duration t_1, delay duration t_2 and/or fire pulse duration t_3 may be selected from those values used to print a particular set or portion of test subpatterns **74** and **76**, in step **112**, or optimized durations t_1, t_2 and/or t_3 may be calculated based on the drop velocity (X,Y) information stored in memory. For example, if drop velocity (A,B), where A is a particular value for X and B is a particular value for Y, is less than a desired value, and drop velocity (A,D), where D is a particular value for Y and is a successor value of B, is higher than the desired value, then a duration t_3 may be used for fire pulse **70** which lies between the duration of the fire pulse associated with fire pulse duration (A,B) and fire pulse duration (A,D).

According to an exemplary embodiment, process **100** is used only to determine an optimal fire duration t_3. According to such an embodiment, pre-fire duration t_1 may then be determined using an algorithm that has as an input the duration of the fire pulse. For example, the pre-fire duration t_1 may be determined as a predetermined ratio of fire duration t_3, such as 3 or 4:1 (e.g., if a fire duration of 800 ns is selected, a pre-fire duration of 200 ns might be used.

If not otherwise indexed through use of the variable X, process **100** may be repeated for printhead **34**. If at least one of printheads **34** or **36** are replaced, then process **100** can be reinitiated for the replaced or both printheads. Process **100** can also be initiated at timed intervals, after a certain number of characters are printed or manually by an operator, for example.

Thus, a controller can determine optimized values for durations t_1, t_2 and/or t_3 based upon the measured information for a particular printhead. The selection of pre-fire pulse duration t_1, delay duration t_2 and fire pulse duration t_3 could be made by the controller to thereby optimize a relationship between drop velocity and the fire energy associated with the printhead. This can reduce the amount of energy supplied to actuators in a particular printhead from that which would need to be supplied by a printer without the present invention. Once optimized values for pre-fire pulse duration t_1, delay duration t_2 and/or fire pulse duration t_3 have been selected, an ink jet printer can continue with its normal printing operations using these optimized pulse durations to selectively actuate individual ones of actuators of the printhead.

While this invention has been described with respect to one embodiment, the present invention can be further modified within the spirit and scope of this disclosure. This application is therefore intended to cover any variations, uses, or adaptations of the invention using its general principles. For example, although an exemplary embodiment was described herein with reference to an energy distribution signal having a profile that included a pre-fire and a fire pulse, the present invention is believed to be equally applicable to other energy distribution signals, such as those having a profile that includes only a single pulse. Further, this application is intended to cover such departures from the present disclosure as come within known or customary practice in the art to which this invention pertains and which fall within the limits of the appended claims.

What is claimed is:

1. A method of adjusting fire energy supplied to an actuator of a printhead of an ink jet printer, comprising:

printing a test pattern on a print media by selectively supplying energy distribution signals to a plurality of actuators of said printhead, said energy distribution signals having distinct energy profiles;

scanning said test pattern to obtain offset values, each of said offset values representative of a distance between at least two corresponding portions of said test pattern;

calculating drop velocities from said offset values; and

selecting from the energy distribution signals an energy distribution signal that corresponds with an optimal one of said drop velocities.

2. The method of claim **1**, wherein said selecting act comprises selecting a duration of a fire pulse of the selected one of said energy distribution signals, said fire pulse having a predetermined amplitude.

3. The method of claim **1**, wherein each of said energy distribution signals comprises a pre-fire pulse and a fire pulse separated by a predetermined delay.

4. The method of claim **1**, further comprising adjusting at least one of a duration of a pre-fire pulse, a delay and a fire pulse used by the printer in normal operation to substantially conform with the selected one of the energy distribution signals.

5. The method of claim **4**, wherein said pre-fire pulse is adjusted using an algorithm that has as an input a duration of said fire pulse.

6. The method of claim **1**, further comprising determining if said drop velocities are greater than a lower limit and less than an upper limit.

7. The method of claim **6**, wherein said lower limit is 200 inches per second and said upper limit is 700 inches per second.

8. An ink jet printer, comprising:

a printhead having actuators that are capable of jetting ink with a drop velocity when an energy distribution signal having a fire energy is supplied;

a sensor; and

a controller capable of communicating with the printhead and said sensor, said controller employing a method comprising:

printing a test pattern on a print media by selectively supplying energy distribution signals to a plurality of the actuators, said energy distribution signals having distinct energy profiles;

scanning said test pattern with the sensor to obtain offset values, each of said offset values representative of a distance between at least two corresponding portions of said test pattern;

calculating drop velocities from said offset values; and

selecting from the energy distribution signals an energy distribution signal that corresponds with an optimal one of said drop velocities.

9. An imaging device, comprising:

a carrier;

a printhead carried by said carrier;

a sensor carried by said carrier; and

a controller communicatively coupled with said printhead and said sensor, said controller configured to print an image on a sheet of print media, said image including a test pattern, said controller employing an energy distribution signal adjustment method to determine an energy profile for said printhead,

wherein said energy distribution signal adjustment method includes:

printing said test pattern using distinct energy profiles;

scanning said test pattern with said sensor to obtain offset values,

wherein a respective one of said offset values is representative of a distance between corresponding portions of said test pattern;

calculating drop velocities corresponding to the distinct energy profiles based on said offset values; and

based on the drop velocities, determining an optimal energy profile, to determine when an incremental change in energy corresponds with a disproportionate change in drop velocity.

10. The imaging device of claim **9**, wherein said determining act includes determining a duration of a fire pulse having a predetermined amplitude.

11. The imaging device of claim **9**, wherein said printing act includes using energy distribution signals, each having one of the distinct energy profiles.

12. The imaging device of claim **10**, wherein a duration of a pre-fire pulse is adjusted using an algorithm that has as an input said duration of said fire pulse.

13. The imaging device of claim **9**, wherein said energy distribution signal adjustment method further comprises determining if said drop velocities are greater than a lower limit and less than an upper limit.

14. A method of optimizing an energy distribution signal for use by a printhead including a plurality of heater elements, comprising:

printing a test pattern using predetermined energy profiles;

scanning said test pattern to obtain offset values, wherein a respective one of said offset values is representative of a distance between corresponding portions of said test pattern;

calculating drop velocities corresponding to the energy profiles based on said offset values;

based on the drop velocities, determining an optimal energy profile, wherein the optimal energy profile is determined by using the drop velocities to determine when an incremental change in energy corresponds with a disproportionate change in drop velocity; and

selecting an energy distribution signal corresponding to said optimal energy profile.

15. A method of optimizing a relationship between fire energy and drop velocity, wherein the fire energy can be supplied to an actuator of a printhead of an ink jet printer in the form of an energy distribution signal to jet ink substantially at the drop velocity, comprising:

printing a test pattern by selectively supplying energy distribution signals to a plurality of actuators of said printhead, said energy distribution signals having distinct energy profiles;

scanning said test pattern to obtain drop velocity information corresponding to the energy distribution signals; and

based on the drop velocity information, determining an energy profile that optimizes the relationship between fire energy and drop velocity.

16. A method of claim **15**, wherein determining an energy profile comprises selecting one of the energy distribution signals supplied in the printing act.

17. A method of claim **15**, wherein determining an energy profile comprises using the drop velocity information to determine when an incremental change in energy corresponds with a disproportionate change in drop velocity.

18. A method of claim **15**, wherein printing a test pattern comprises printing a respective set of test subpatterns using a respective one of the energy distribution signals for each set.

19. A method of claim **18**, wherein scanning comprises scanning the test pattern to obtain an offset value for each of the sets, wherein the offset value for a respective one of the sets is representative of a distance between at least two corresponding portions in the respective one of the sets, and wherein the drop velocity information comprises drop velocities determined from the obtained offset values.

20. A method of claim **15**, wherein printing a test pattern comprises printing test subpatterns, each of the subpatterns comprising blocks, each of the blocks in one of the subpatterns corresponding with a block in another one of the subpatterns, and wherein corresponding blocks are printed using a respective one of the energy distribution signals.

21. A method of claim **20**, wherein scanning comprises scanning the test pattern to obtain an offset value for each set of corresponding blocks, wherein the offset value for a respective one of the sets is representative of a distance between at least two corresponding portions in the respective one of the sets, and wherein the drop velocity information comprises drop velocities determined from the obtained offset values.

22. A method of claim **15**, wherein drop velocity information comprises offset values each representative of a distance between at least two corresponding portions of the test pattern.

23. A method of claim **15**, wherein determining an energy profile comprises calculating an optimal duration of a pulse to be used in an energy distribution signal to be used with the printhead during normal operation, wherein the optimal duration is calculated based on the drop velocity information.

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